TITLE: REACTIVATION OF AN IDLE LEASE TO INCREASE HEAVY OIL RECOVERY THROUGH APPLICATION OF CONVENTIONAL STEAM DRIVE TECHNOLOGY IN A LOW DIP SLOPE AND BASIN RESERVOIR IN THE MIDWAY-SUNSET FIELD, SAN JAOQUIN BASIN, CALIFORNIA

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Objective

A previously idle portion of the Midway-Sunset field, the ARCO Western Energy Pru Fee property, is being brought back into commercial production through tight integration of geologic characterization geostatistical modeling, reservoir simulation, and petroleum engineering. This property, shut-in over a decade ago as economically marginal using conventional cyclic steaming methods, has a 200-300 foot thick oil column in the Monarch Sand. However, the sand lacks effective steam barriers and has a thick water-saturation zone above the oil-water contact. These factors require an innovative approach to steam flood production design that will balance optimal total oil production against economically viable steam-oil ratios and production rates. The methods used in the Class III demonstration are accessible to most operators in the Midway-Sunset field and could be used to revitalize properties with declining production of heavy oils throughout the region.

The 40 ac Pru Fee property is located in the super-giant Midway-Sunset field and produces from the late Miocene Monarch Sand, part of the Monterey Formation. The Midway-Sunset field was discovered prior to 1890. Cumulative production from the field through 1995 was 2.3 billion barrels of oil and 563 billion cubic feet of gas, with remaining reserves estimated to exceed 450 MMBO. The average daily field production in 1995 was 163,400 barrels of oil. In the Pru Fee property, now held by ARCO Western

Energy, cyclic steaming was used to produce 13° API oil. However, the previous operator was unable to develop profitably this marginal portion of the Midway-Sunset field using standard enhanced oil recovery technologies and chose rather to leave more than 3.0 MMBO of oil in the ground that otherwise might have been produced from the 40 ac property. Only 927 MBO had been produced from the property when it was shut-in in 1987. This is less than 10% of the original oil-in-place, which is insignificant compared to typical heavy oil recoveries in the Midway-Sunset field of 40 to 70%. The objective of the demonstration project is to encourage a similar incremental increase in production in all other marginal properties in the Midway-Sunset and adjacent fields in the southern San Joaquin Basin.

In January 1997 the project entered its second and main phase with the purpose of demonstrating whether steamflood can be a more effective mode of production of the heavy, viscous oils from the Monarch Sand reservoir than the more conventional cyclic steaming. The objective is not just to produce the pilot site within the Pru Fee property south of Taft (Figure 1), but to test which production parameters optimize total oil recovery at economically acceptable rates of production and production costs.

Well Drilling and Completions

During the period January 19 through April 11, 18 new wells (Table 1) were drilled and completed at the 8 ac pilot near the center of the Pru property (Fig. 2). Together with Pru 101, which was drilled in 1995 during the evaluation phase of the project, and eight older wells renovated and put on cyclic production at the start of the project, these wells form a four-fold, nine-spot well pattern. The older wells are B-1, 533, B-3, 12, C-2, C-3, D-1 and D-2. Each injector is surrounded by 8 producers located at the corners and middle edges of a square. Four squares are joined to form a larger square approximately 600 ft by 700 ft, or about 8 ac in size. Along the north edge of the array, a producer is missing from the ideal array between wells 533 and 201. The need to accommodate existing wells into the array has resulted in a departure from an ideal Cartesian spacing of the wells. About half of the producers, those in the interior of the array, are in potential communication with two or more injectors. In addition to the 24 wells in the production array, there are four temperature observation wells, each positioned within 80-180 ft of an injector. One of the temperature observation wells, Pru TO-1, was drilled during the initial phase of the project to monitor cyclic steaming in Pru 101. The other three wells were drilled at the start of the demonstration phase.

The injector and temperature observation wells were drilled and completed in a similar fashion. A 6.5 in hole was directionally drilled to about 100 ft below the projected oil-water contact (OWC) and Schlumberger *Platform Express* run in the open hole. A 3.5 in casing was positioned from the surface to the base of the hole (TD), baffled at a depth 32 ft above TD, and cemented in place. The circulation and casing of the wells was done by Halliburton. The casing in the injectors was perforated (Table 2) at six locations about 10 ft apart. This 47 to 60 ft interval of perforations was positioned 131 to 202 ft above the OWC and 39 to 47 ft below the top of the Monarch sand.

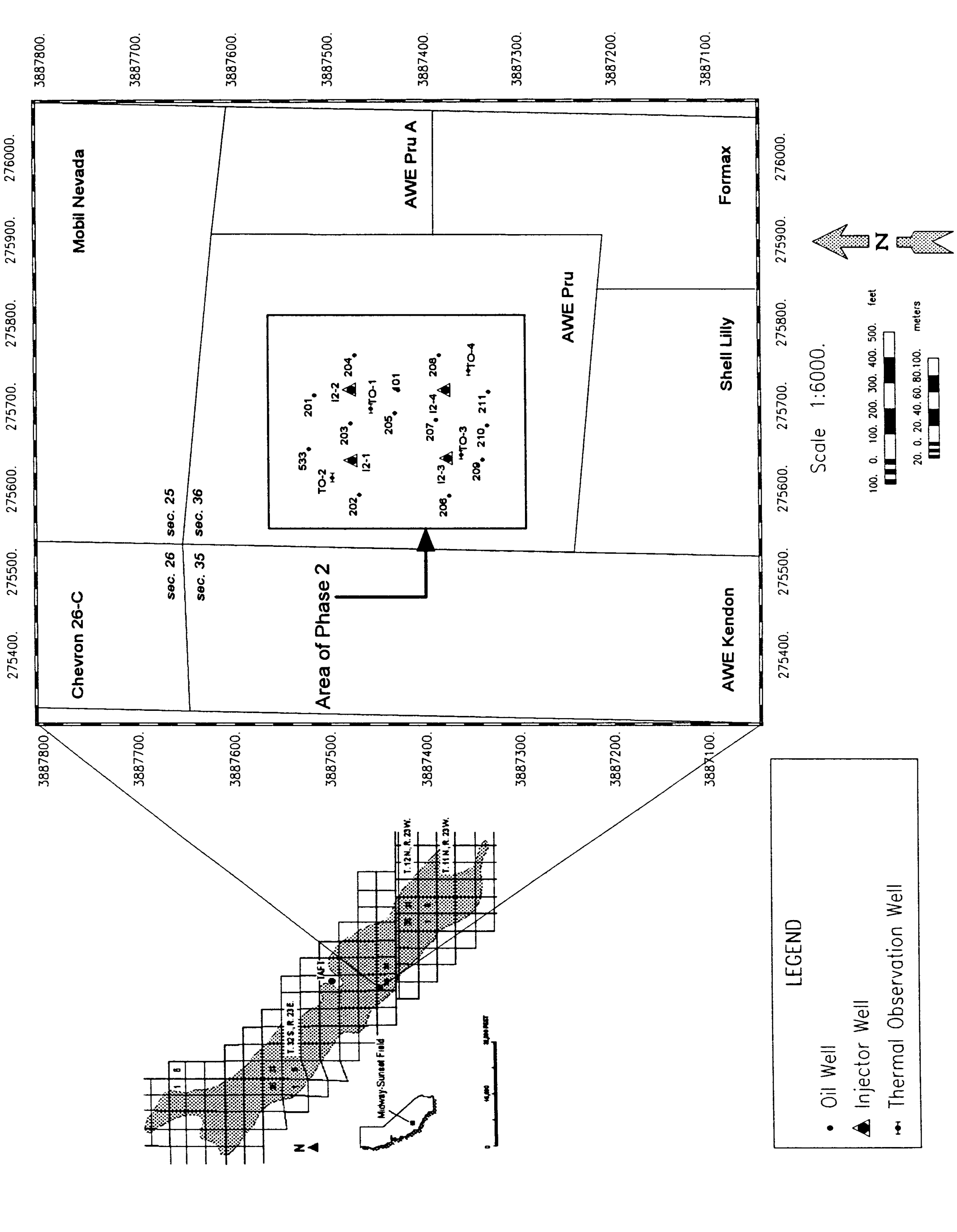

Figure 1. The Pru project encompasses the AWE Pru and adjacent leases. Wells used for the stratigraphic characterization in Phase 2 are within the AWE Pru lease. Map coordinates are in UTMs, zone 11.

Drilling and completion of the producers was more complicated. A 9 7/8 in hole was directionally drilled to a depth approximately 100 ft below the projected OWC. Schlumberger *Platform Express* was run in the open hole. A 7.0 in solid casing (23# J-55 LTC) was inserted to a depth about 25 ft below the top of the Monarch Sand, cemented in place and a 7 in wellhead installed. The float and cement at the base of the solid casing was drilled out and the remainder of the open hole through the Monarch Sand to TD was reamed out to a 13.0 in diameter. A 5.5 in liner was inserted inside of the casing to a depth 5 to 50 ft above TD and packed in place with 8 x 12 gravel. Gravel also fills the hole below the hole below the bottom of the liner to TD. The upper section of the liner above the base of the casing and the lower section from 30 ft above the OWC to the lower end is blank. A short segment near the base of the casing is semi-perforated. The remaining section of liner, the longer section through the Monarch Sand, is slotted. Within one or two weeks after release of the rig, tubing, rods and a pump were installed and the well run on production.

Each producer was primed by steaming before putting in full production mode. The target steam volume was 8,000 BS and the target rate 1,000 BSPD. However, the actual steam rates varied from 650 to 1,250 BSPD. Generally, the wells were soaked for 2 weeks after the steam jobs. The priming of the new producers began in March and was completed by the end of May, 1997.

The Schlumberger *Platform Express* runs include array induction, SP, temperature, density, neutron density, and gamma ray logs.

Production at the Pru Pilot

In Fall 1995, as the first phase of the project began, eight (8) old production wells were renovated and a new producer, Pru 101, was drilled. After an initial cycle of steaming in the period of October-December 1995, all nine wells were put on production (Fig. 3) as the cyclic baseline test. The eight old wells are those now included in the pilot array described above. Initial production, except from Pru 101 (Fig. 4), was generally poor. The wells were steamed again in February-May 1996, and yet again in July-August 1996. In general, rates improved during this period of repeated stimulation and continued production. During the cyclic test period, production averaged for the total group of nine wells about 70 BOD, ranging from 3 to 10 BOD/well for the old wells and about 15 BOD for Pru 101. The average production rate for the nine cyclic producers through the end of 1996 was about 8 BOD/well. The total production rate had begun to decline in the last months of 1996.

In the period January 11 through April 11, 1997 eleven (11) new producers were drilled. Each was primed by steaming in turn during March-May and immediately put into production. The result was nearly an order of magnitude increase in production rate from 50-60 BOD to nearly 400 BOD (Fig. 3). The sharp increase in production can, in part, be attributed to the increase in the number of producers from nine to twenty and the fact that the performance of the new wells is consistently better than the old renovated wells (Figs. 5 and 6. However, the well average jumped from about 8 BOD to nearly 20 BOD with the onset of the pilot steam flood. It anticipated that the performance will continue to improve as the steam chest builds within the demonstration site.

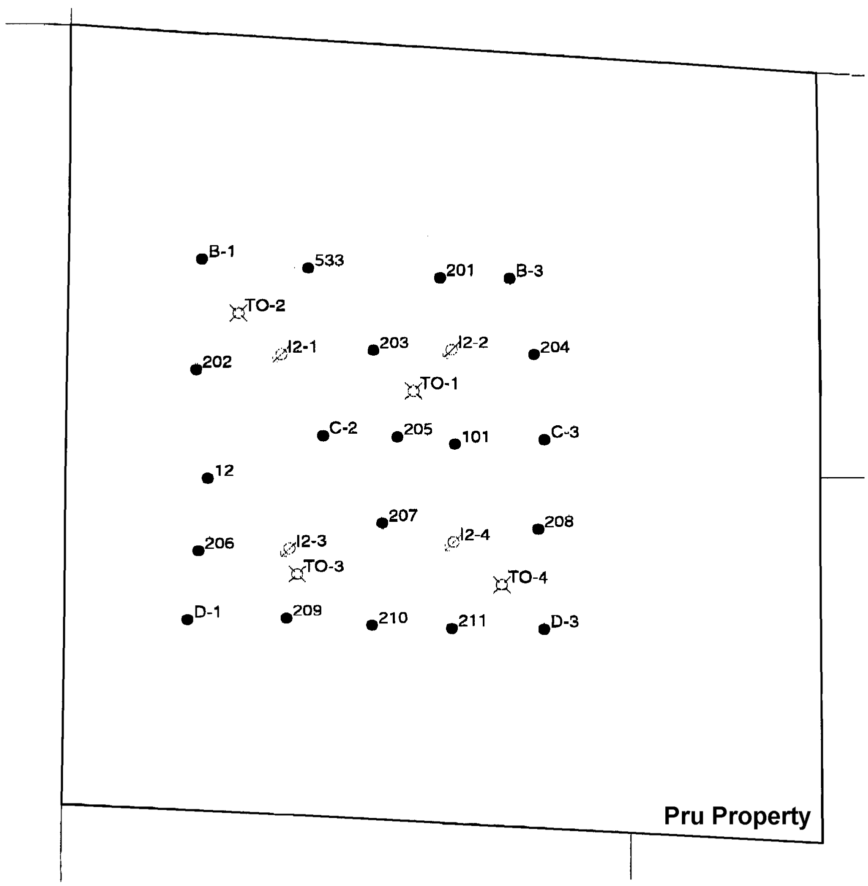

Figure 2: Production array for the 8 ac pilot steamflood demonstration on the Pru property. The Pru property is a total of 40 ac in size. The array of wells occupies a space approximately 160 ft by 170 ft.

Table 1

MIDWAY-SUNSET FIELD CLASS III OIL TECHNOLOGY DEMONSTRATION PROJECT

ARCO Western Energy Pru Property: Section 36 Township 32S Range 23 E

Wells Drilled for the 8 ac Pilot Demonstration in Center of Property

Well Name	API Serial No.	Spud Date	Prod. Date	TD (ft)	KB (ft)	GL (ft)
Pru 101	04030-04475	9/16/95	10/11/95	1402	1394	1381
Pru 201	04030-07115	1/19/97	2/13/97	1512	1429	1416
Pru 202	04030-07114	1/27/97	4/11/97	1500	1383	1370
Pru 203	04030-07113	2/9/97	2/25/97	1497	1418	1405
Pru 204	04030-07112	2/6/97	2/15/97	1476	1393	1380
Pru 205	04030-07111	2/13/97	3/7/97	1468	1383	1370
Pru 206	04030-07110	2/20/97	3/28/97	1483	1399	1386
Pru 207	04030-07109	3/13/97	3/30/97	1452	1371	1358
Pru 208	04030-07108	2/9/97	3/4/97	1462	1372	1359
Pru 209	04030-07107	2/25/97	3/24/97	1482	1398	1385
Pru210	04030-07106	3/8/97	3/30/97	1400	1380	1367
Pru 211	04030-07105	3/1/97	3/23/97	1415	1355	1342
Pru I 2-1	04030-07151	2/17/97	NA	1471	1383	1370
Pru I 2-2	04030-07152	1/24/97	NA	1486	1393	1380
Pru I 2-3	04030-07153	3/11/97	NA	1464	1381	1368
Pru I 2-4	04030-07154	3/6/97	NA	1441	1359	1346
Pru TO-1	04030-04476	9/14/95	NA	1529	1394	1381
Pru TO-2	04030-07155	1/17/97	NA	1529	1445	1432
Pru TO-3	04030-07156	2/22/97	NA	1485	1398	1385
Pru TO-4	04030-07157	3/4/97	NA	1434	1355	1342

Table 2
Depths of Perforations in Injector Wells in the Pilot Demonstrtation

Well Name	Top Monarch	Perforations (ft)						OWC (ft)
Pru I2-1	1057	1104	1116	1123	1134	1142	1160	1362
Pru I2-2	1088	1127	1136	1142	1150	1160	1174	1361
Pru I2-3	1102	1149	1164	1177	1183	1200	1209	1367
Pru I2-4	1106	1150	1163	1178	1185	1198	1206	1337

Note: All well depths are in feet down hole, not TVD.

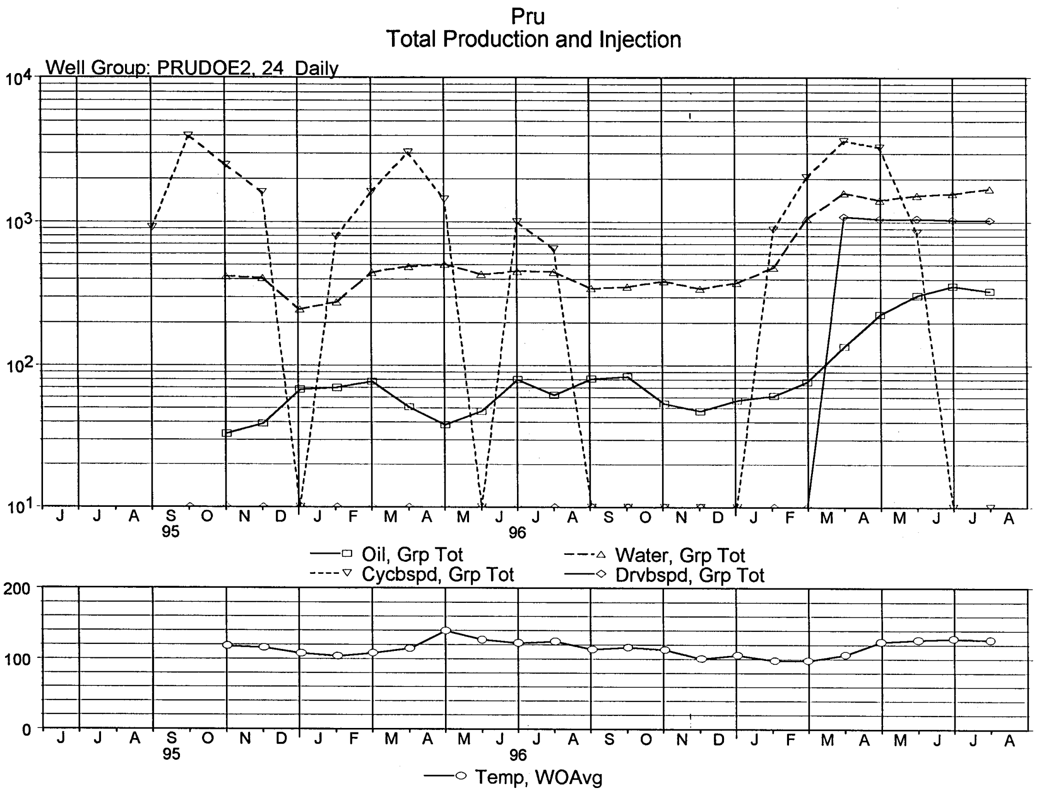

Figure 3: Total production from the Pru demonstration site through summer 1997

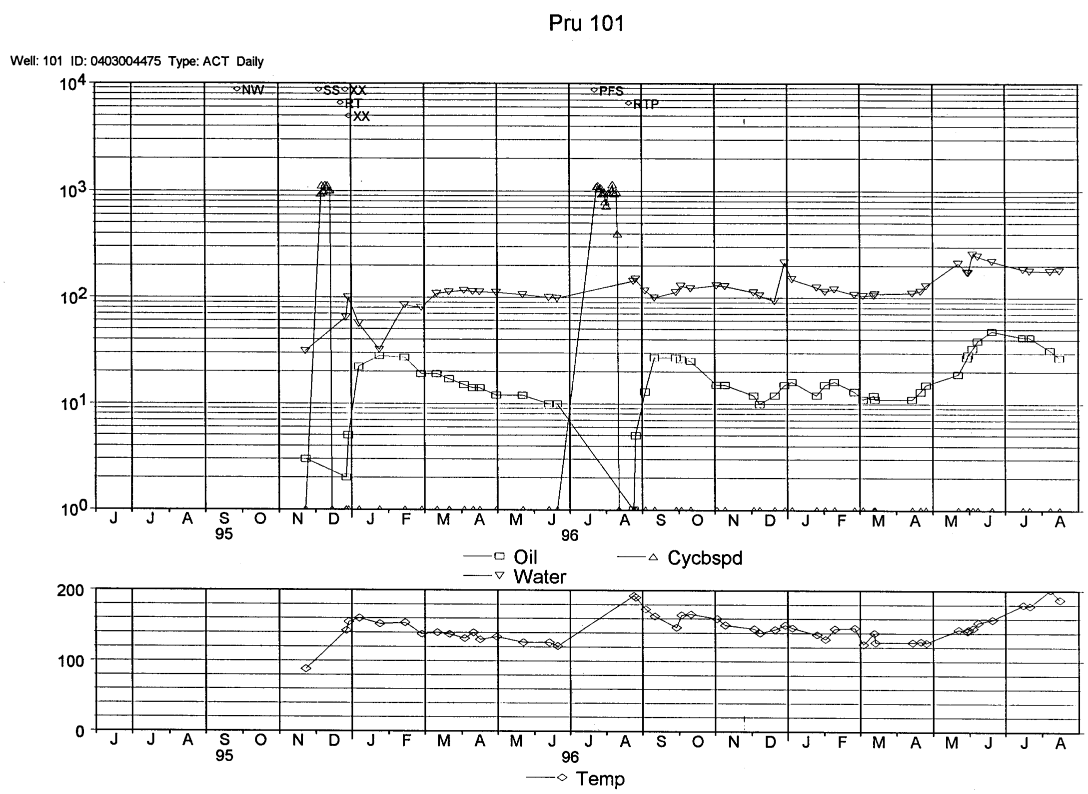

Figure 4: Production from Pru 101 through summer 1997

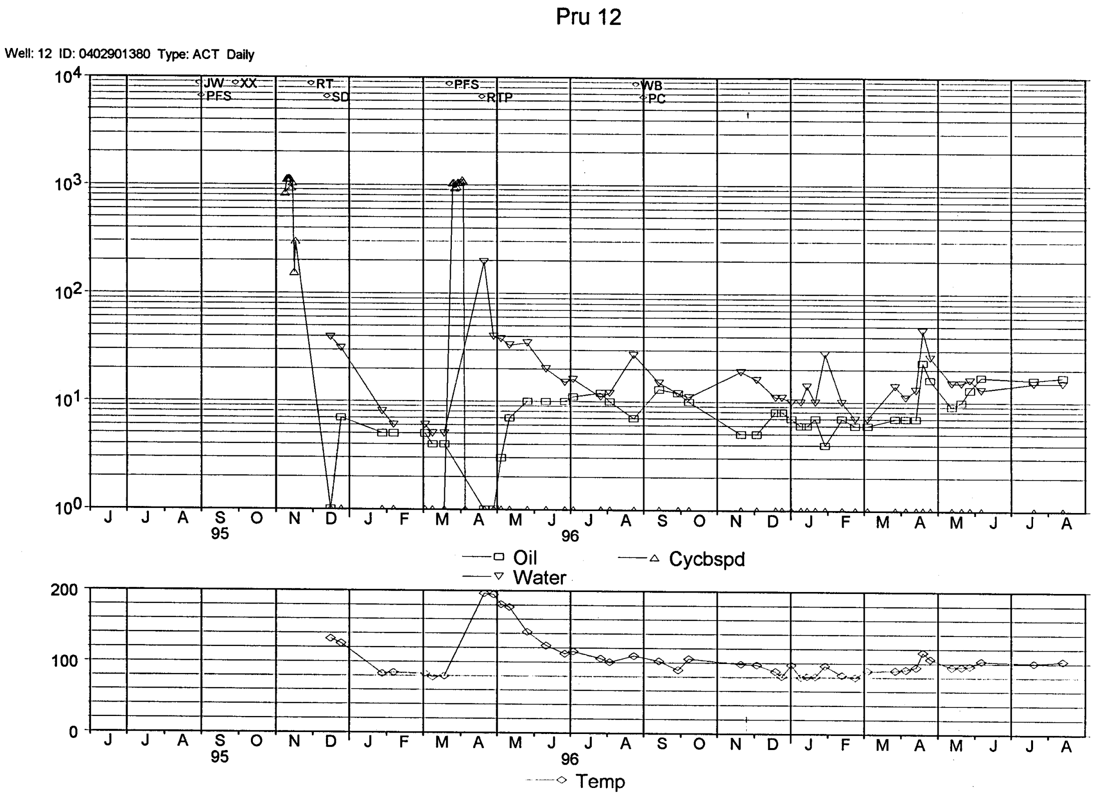

Figure 5: Production from Pru 12, an old well, through summer 1997.

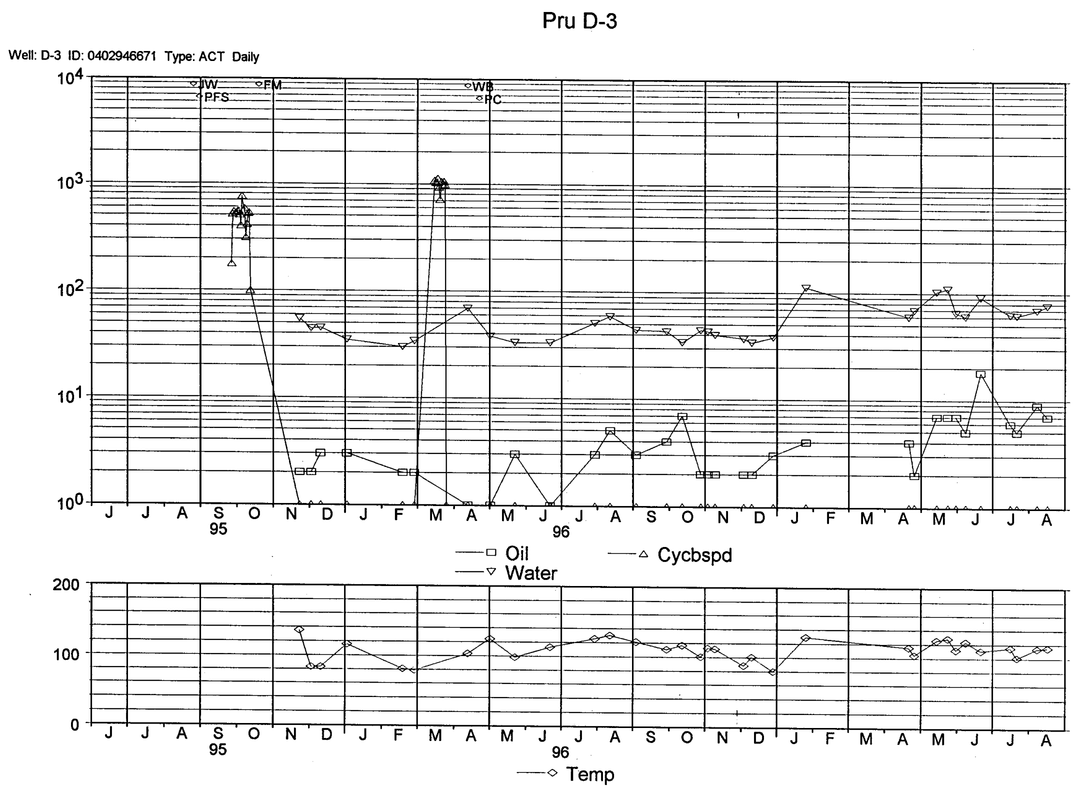

Figure 6: Production from Pru D-3, an old well, through summer 1997.

Reservoir Simulation Activity

Reservoir simulations with geostatistically generated data sets revealed that the initial fluid distribution in the reservoir had the most significant impact on the economics of the cyclic-flooding process. The initial fluid distribution was determined by the placement of the oil-water contact and the resulting transition zone in the reservoir. In order to avoid heating and moving large amounts of water by injecting into the transition zone a new completion strategy was recommended. The new completion method was to complete both the injectors and producers a certain distance over the oil-water contact (OWC). The optimum completion for the specific reservoir model used was determined to be about 75-100 feet above the OWC. The optimum stand-off above the OWC depended on the oil-water contact itself. The OWC in all completion simulations was at 1400 feet. Since the nature of the oil-water transition zone was so important in process economics, sensitivity of basic oil production parameters to the location of OWC was examined. In this report, production parameters for OWC locations of 1400 feet, 1420 feet and 1350 feet are compared.

The Reservoir Model

Porosity, permeabilities and thicknesses generated using the geostatistical methods described previously were used in the model. Other basic model characteristics are listed in Table 3.

Table 3-Basic features of the reservoir model

Area simulated	Quarter of an inverted nine-spot pattern
Pattern	Two-acre inverted nine spot
Grid	Cartesian, 10X10X20

When the OWC was moved from 1400 feet to 1350 feet, the initial fluid distribution in the reservoir changed. The initial fluids in place in the reservoir are given in Table 4 for the three cases.

Table 4-Initial fluids in place for the two models

Parameter	OWC – 1400 feet	OWC – 1350 feet	OWC – 1420 feet
Initial water in place	1.987 E+05	2.433 E+05	1.662 E+05
Average water saturation	0.56	0.68	0.47

Simulation Results

Cumulative oil productions for the three cases are compared in Figure 7. The oil production drops drastically (from about 50,000 barrels to about 13,000 barrels) as the water oil contact is moved upward. The variations of oil-steam ratios with time are compared in Figure 8. The peak oil-steam ratio for the higher OWC drops below 0.1, making the process essentially uneconomic.

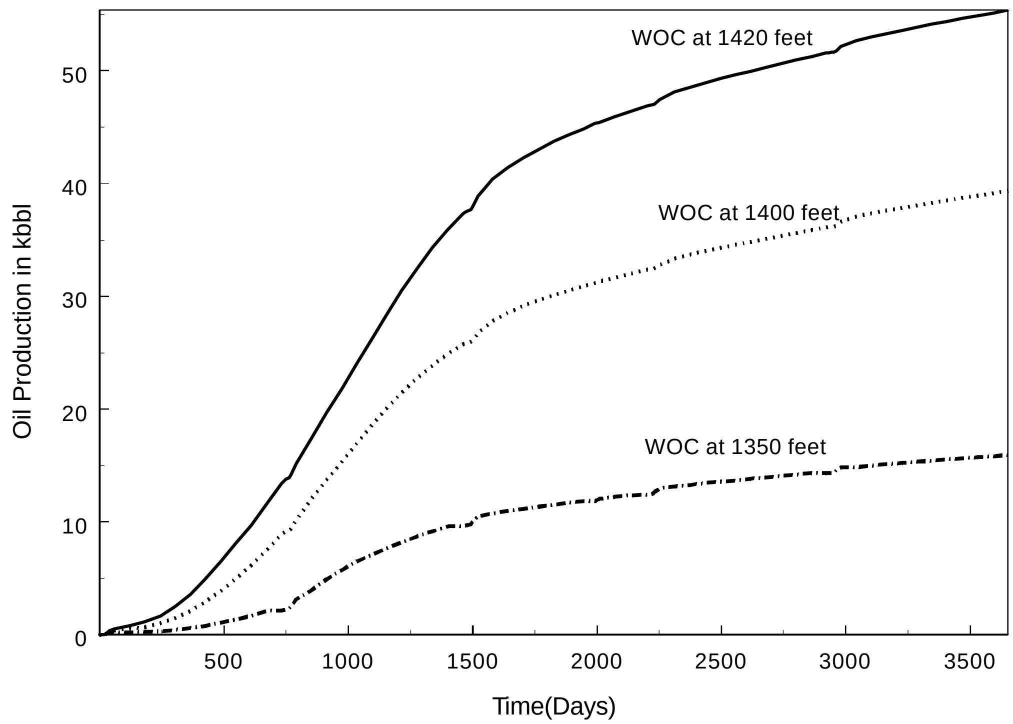

Figure 7: Cumulative oil production rates for the three water-oil contacts

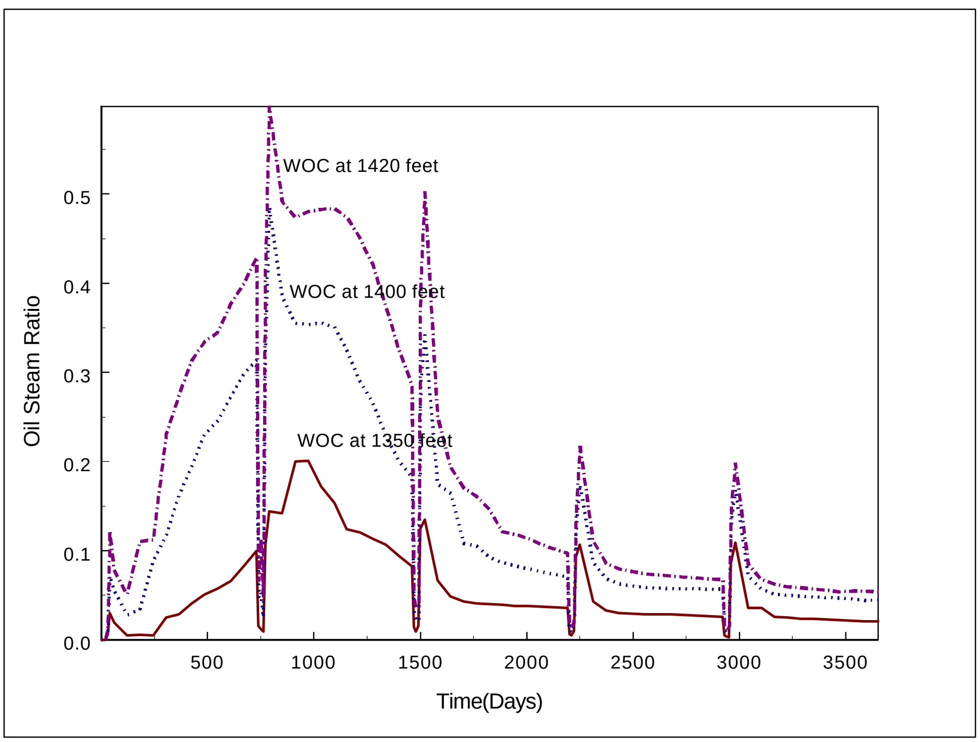

Figure 8: Comparison of oil-steam ratios for the three water-oil contacts.

Technology Transfer

At the 1997 annual convention of the American Association of Petroleum Geologists (AAPG) in Dallas, Texas, April 6-9, the project team presented an invited paper in the session *Results of Joint DOE/Industry Programs*. The poster paper entitled "Enhanced oil recovery in the Midway-Sunset Field, San Joaquin Basin, California: A DOE Class III Oil Technology Demonstration Project" summarized the purpose of the project and the technical results to date. By invitation, the same poster paper was presented at the annual meeting of the San Joaquin Geological Society, an AAPG affiliate society, in Bakersfield, California in mid-May, 1997.

The goals and status of the project were presented at a DOE Contractors Conference sponsored by the *National Petroleum Technology Office* in June 1997. The week-long conference was held in Houston, Texas.